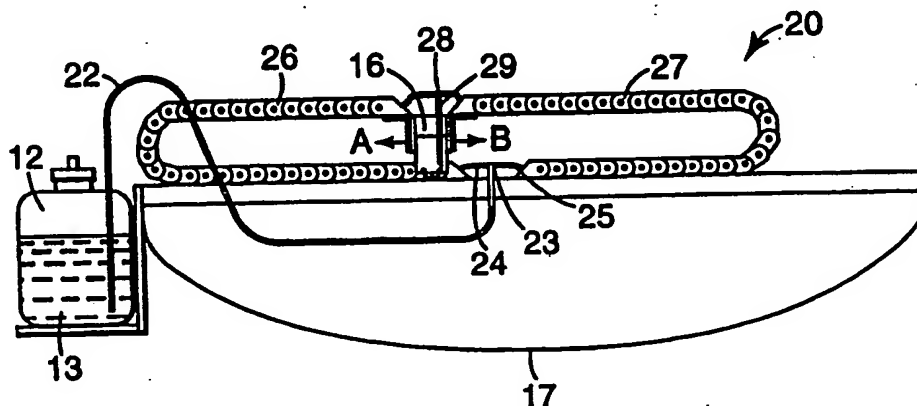




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : B41J 2/175	A1	(11) International Publication Number: WO 99/42293 (43) International Publication Date: 26 August 1999 (26.08.99)
<p>(21) International Application Number: PCT/US98/13827</p> <p>(22) International Filing Date: 2 July 1998 (02.07.98)</p> <p>(30) Priority Data: 09/025,166 18 February 1998 (18.02.98) US</p> <p>(71) Applicant: MINNESOTA MINING AND MANUFACTURING COMPANY [US/US]; 3M Center, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).</p> <p>(72) Inventors: HU, Jia; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). LEE, Charles, C.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). KOEHLER, Bruce, H.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US).</p> <p>(74) Agents: HORNICKEL, John, H. et al.; Minnesota Mining and Manufacturing Company, Office of Intellectual Property Counsel, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).</p>	<p>(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).</p> <p>Published <i>With international search report.</i></p>	

(54) Title: **PRESSURE BALANCED LOOP FLUID DELIVERY SYSTEM AND METHOD FOR USING SAME**

(57) Abstract

A pressure balanced loop fluid delivery system is provided to counteract pressure variations as an inkjet printer head abruptly moves, causing acceleration or deceleration. The fluid loop avoids undue positive or negative pressures for fluids being delivered to the print head that are present in conventional fluid delivery systems that move tubing in both directions of a print head along the width of an inkjet printer.

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Pressure Balanced Loop Fluid Delivery System and Method for Using Same

Field of Invention

5 The present invention relates to a fluid delivery system, principally for inkjet printers.

Background of Invention

10 Image graphics are omnipresent in modern life. Images and data that warn, educate, entertain, advertise, etc. are applied on a variety of interior and exterior, vertical and horizontal surfaces. Nonlimiting examples of image graphics range from advertisements on walls or sides of trucks, posters that advertise the arrival of a new movie, warning signs near the edges of stairways.

15 The use of thermal and piezo inkjet inks have greatly increased in recent years with accelerated development of inexpensive and efficient inkjet printers, ink delivery systems, and the like.

20 Thermal inkjet hardware is commercially available from a number of multinational companies, including without limitation, Hewlett-Packard Corporation of Palo Alto, CA, USA; Encad Corporation of San Diego, CA, USA; Xerox Corporation of Rochester, NY, USA; LaserMaster Corporation of Eden Prairie, MN, USA; and Mimaki Engineering Co., Ltd. of Tokyo, Japan. The number and variety of printers changes rapidly as printer makers are constantly improving their products for consumers. Printers are made both in desk-top size and wide format size depending on the size of the finished image graphic desired.

25 Nonlimiting examples of popular commercial scale thermal inkjet printers are Encad's NovaJet Pro and Pro E printers and H-P's 650C, 750C, and 2500CP printers. Nonlimiting examples of popular wide format thermal inkjet printers include H-P's DesignJet printers, where the 2500CP is preferred because it has 600X600 dots/inch (dpi) resolution with a drop size in the vicinity of about 40

30 picoliters.

Piezo inkjet hardware is commercially available from a number of multinational companies, including without limitation, Olympus Optical Co. of Tokyo, Japan; Idanit Technologies Ltd of Rishon Le Zion 75150 Israel; Seiko Epson Corp. of Nagano, Japan; Calcomp, Inc. of Anaheim, CA, USA; Raster Graphics, Inc. of San Jose, CA, USA; and Vutek of Concord, NH, USA.

3M markets Graphic Maker Inkjet software useful in converting digital images from the Internet, ClipArt, or Digital Camera sources into signals to thermal inkjet printers to print such image graphics.

Inkjet inks are also commercially available from a number of multinational companies, particularly 3M which markets its Series 8551; 8552; 8553; and 8554 pigmented inkjet inks. The use of four principal colors: cyan, magenta, yellow, and black (generally abbreviated "CMYK") permit the formation of as many as 256 gray levels per color or more in the digital image.

Media for inkjet printers are also undergoing accelerated development. Because inkjet imaging techniques have become vastly popular in commercial and consumer applications, the ability to use a personal computer to print a color image on paper or other receptor media has extended from dye-based inks to pigment-based inks. And the media must accommodate that change. Pigment-based inks provide more durable images because pigment particles are contained in a dispersion before being dispensed using a thermal inkjet print head.

Inkjet printers have come into general use for wide-format electronic printing for applications such as, engineering and architectural drawings. Because of the simplicity of operation and economy of inkjet printers, this image process holds a superior growth potential promise for the printing industry to produce wide format, image on demand, presentation quality graphics.

Therefore, the components of an inkjet system used for making graphics can be grouped into three major categories:

- 1 Computer, software, printer.
- 2 Ink.
- 3 Receptor medium.

The computer, software, and printer will control the size, number and placement of the ink drops and will transport the receptor medium through the printer. The ink will contain the colorant which forms the image and carrier for that colorant. The receptor medium provides the repository which accepts and
5 holds the ink. The quality of the inkjet image is a function of the total system. However, the composition and interaction between the ink and receptor medium is most important in an inkjet system.

Image quality is what the viewing public and paying customers will want and demand to see. From the producer of the image graphic, many other
10 obscure demands are also placed on the inkjet media/ink system from the print shop. Also, exposure to the environment can place additional demands on the media and ink (depending on the application of the graphic).

Current inkjet receptor media are direct coated with a dual layer receptor according to the disclosure contained in PCT International Patent
15 Publication WO97/17207 (Warner et al.) and are marketed by 3M under the brands 3M™ Scotchcal™ Opaque Imaging Media 3657-10 and 3M™ Scotchcal™ Translucent Imaging Media 3637-20. Another inkjet receptor media is disclosed in PCT Publication WO97/33758 which combines a hygroscopic layer on a hydrophilic microporous media.

20 Inkjet inks are typically wholly or partially water-based, such as disclosed in U.S. Pat. No. 5,271,765, or solvent based or ultraviolet curable. Typical receptors for these inks are plain papers or preferably specialist inkjet receptor papers which are treated or coated to improve their receptor properties or the quality of the images resulting therefrom, such as disclosed in U.S. Pat. No.
25 5,213,873.

Delivery of ink from a reservoir to an inkjet print head is presently preferred because the ability to store larger volumes of ink than contained in the print head is critical to the printing of large images typically as wide as 1-1.25 meters. An example of an ink delivery system is disclosed in PCT Publication
30 WO97/10106 (Lee et al.).

The transit of the inkjet print heads across a wide format inkjet printer typically employs some type of ink supply support system, such as disclosed in U.S. Pat. No. 5,469,201 (Erickson et al.). However, some problems in ink delivery from reservoir to print head develop in such ink supply support systems.

Summary of Invention

Source of the Problem

The present invention solves problems unrecognized in the art of ink supply systems in an unexpected way.

In typical fluid delivery systems for large format ink jet printers such as the LaserMaster Big Ink system (LaserMaster Corporation, Eden Prairie, MN, USA), the Colossal Graphics Bulk Ink system (Colossal Graphic of Palo Alto, CA, USA), the Encad NovaJet Pro and Pro E series fluid delivery systems (Encad Corporation, San Diego, CA, USA), and the 3M Ink Delivery System (Minnesota Mining and Manufacturing Company (3M), St. Paul, MN, USA), among others, ink (i.e., a fluid) is delivered from stationary supply tanks to the print heads (i.e., reciprocating dispensers) via flexible tubing (i.e., fluid lines). The tubing is protected and directed in its motion by enclosing the tubing in a segmented plastic chain type cable guide. This fluid line configuration is common to all the fluid delivery systems mentioned above.

The present invention solves the following problem: A drawback of this configuration in conventional fluid delivery systems is that the fluid pressure at the print head varies due to acceleration and deceleration of the fluid lines as the print head starts, stops, or changes direction. If the head is stationary, the fluid supply line is also stationary, and if the head is not printing, the fluid flow is zero. In this case, the pressure in the print head is determined by the density of the fluid, and by the height difference between the fluid surface in the supply tank and the print head orifice plate. In a conventional prior art fluid delivery system where the reservoir is to the left of the print head such as that seen in Fig. 1 described below, if the head is accelerated to the right, fluid will be forced into the print head

because the print head is accelerating toward the fluid in the line. The pressure inside the print head will rise during acceleration to the right. If the print head is accelerated to the left, fluid will be drawn out of the print head because the print head is accelerating away from the fluid in the line, and the internal pressure will
5 drop.

These pressure fluctuations can affect adversely the jetting performance of the print head. Typically the fluid surface in the supply tank is below the print head orifice (nozzle) plate, so the pressure in the print head is slightly below atmospheric pressure. This slight negative pressure helps keep fluid
10 from dripping out of the print head nozzles and flooding the orifice plate. Capillary forces between the fluid and the nozzles keep the fluid from being pulled out of the nozzles and back into the supply tank. However, if the fluid surface in the supply tank is so low that the negative pressure in the print head exceeds the capillary forces between the fluid and the nozzles, the fluid will be pulled out of the nozzles
15 where air can enter, and the fluid will flow back into the supply tank.

The relationship between the negative pressure in the print head and the capillary forces between the fluid and the nozzles also affects the refill rate of the nozzles. Even if the negative pressure in the print head is not enough to draw fluid out of the nozzles, it could be enough to slow the nozzle refill rate, thereby
20 significantly lowering the maximum firing frequency of the print head. Pressure fluctuations inside the print head due to acceleration and deceleration of the fluid lines can cause momentary problems with orifice plate flooding, nozzle refill rate and nozzle evacuation during printing. These anomalies will seriously affect the quality of the printed image.

25 In fluid delivery systems that use the conventional approach, the pressure fluctuations in the print head due to acceleration and deceleration can be reduced by keeping a pocket of air inside the print head. In systems like the Encad NovaJet Pro printer, this is done by only filling the print cartridge partially full and then connecting the fluid supply line to the cartridge. In other systems, the print
30 head cartridge itself may have an air bladder inside, which serves to dampen pressure fluctuations. The air pocket works because air is compressible. The fluid

inlet to the cartridge is typically quite small (approximately 2mm diameter) which restricts the flow rate into or out of the cartridge. If the cartridge is accelerating to the right, fluid is forced into the cartridge but at a relatively low flow rate. If the fluid is flowing into the cartridge at $2 \text{ cm}^3/\text{sec}$ during a 1 second acceleration, 2 cm^3 of fluid will enter the cartridge if there is an air pocket in the cartridge. If the volume of the air pocket was 30 cm^3 , it will be compressed to a volume of 28 cm^3 after the fluid enters. This compression will result in a slightly higher pressure in the cartridge, (about $30/28=1.07$ times higher). However, if the cartridge had a very small air pocket, or none at all, the pressure increase would be much higher.

Actually the pressure increase is related to many things, acceleration, flow rate, mass of fluid in the moving line, bending of the fluid lines, fluid viscosity, etc. and is quite complicated. Print quality is unacceptable if a conventional fluid delivery system is used without an air pocket or air bladder inside the print head cartridge.

While an air pocket or an air bladder does help reduce the pressure fluctuations within a print head during acceleration and deceleration, it can be a source of problems. To get the air pocket in the NovaJet Pro system, one has to partially fill the cartridge with fluid, and then fill the fluid line before connecting the line to the cartridge. It is difficult and often messy to get the right amount of fluid into the cartridge so the size of the air pocket will be correct. The cartridge has opaque walls so one can not see how much ink is in the cartridge. When a cartridge with an air pocket is removed for cleaning, sometimes the supply line end inside the cartridge comes out of the fluid and into the air pocket when the cartridge is tipped. Air can enter the supply line and de-prime the system. A print head cartridge typically has a filter screen at the bottom that filters large particles from the fluid before it enters a small chamber between the screen and the nozzles. The air in this chamber can never be completely removed, because air bubbles in the small chamber float up and rest against the underside of the screen. These air bubbles can restrict the flow of fluid through the screen and affect areas of the image where the fluid demand is high.

If the air pocket in the print head cartridge were not required, it would be much easier for the user to prime the system by pressure, without getting

air trapped in the filtered chamber. For example, if no air pocket is required, priming is done by connecting the fluid line to the cartridge, holding the cartridge upside down (nozzles up), and then forcing fluid into the cartridge by pressurizing the supply tank. As fluid enters the cartridge, air escapes from the nozzles. When
5 fluid starts coming out of the nozzles, the cartridge is full with little or no air trapped in the filtered chamber. The user then depressurizes the supply tank, blots the nozzles with a paper towel, and inserts the cartridge into the printer carriage. These procedures are described in the users manual for the 3M 8592 Ink Delivery System for Mimaki TIJ-50 and NovaJet III printers.

10 Some systems use print heads that do not have an integral reservoir. For these systems, an external reservoir that moves with the print head is used to reduce pressure transients due to acceleration and deceleration of the fluid lines. Some of these systems use float switches or level sensors to keep constant the fluid in the reservoirs by controlling fluid pumps that refill the reservoirs when the level
15 is low. These systems use more components that are in contact with the fluid, and each of these components has to be compatible with the fluid. This is particularly troublesome with solvent based fluids.

Solution to the Discovered Problem

The present invention provides a pressure balanced loop fluid
20 delivery system.

One aspect of the invention is a fluid line configuration for supplying fluid to reciprocating fluid dispensers from stationary fluid supply tanks. The balanced loop fluid line configuration of the present invention substantially reduces pressure transients at the reciprocating dispensers due to acceleration or
25 deceleration of the dispensers and tubing. The fluid delivery system comprises a pressure balanced loop of tubing containing fluid therein.

More particularly, the pressure balanced loop fluid delivery is built by constructing a loop of tubing carried by a loop of cable/hose carriers. At the top and the bottom of the loop, there is a tee in the tubing. The top tee goes to the
30 reciprocating dispenser, and the bottom tee goes to the stationary fluid supply tank. Fluid is free to circulate within the loop, thereby substantially reducing pressure

surge transients in the reciprocating dispensers when the dispensers and tubing are accelerated or decelerated. This construction solves the problems in the prior art fluid delivery systems described above.

Another aspect of the present invention is an inkjet printer
5 comprising a pressure balanced loop fluid delivery system described above.

Yet another aspect of the present invention is a method of using the inkjet printer containing a pressure balanced loop fluid delivery system described above.

A feature of the present invention is presence of a loop in the fluid
10 delivery system that compensates changes in pressure, regardless of the configuration of the ink reservoir or the print head.

An advantage of the present invention is that pressure is compensated during acceleration or deceleration without need for complicated or expensive equipment.

15 Another advantage of the present invention is an improved jetting performance of ink through the delivery system and the print head, typically most pronounced at the edges of the printed media, at which edges the delivery system is undergoing greatest change in acceleration as the print head slows, stops, and reverses direction in the printer.

20 Another advantage of the present invention is the ability to print images in both directions of the print head across the imaged media without difficulty at the edges of such media.

Further features and advantages will be described with references to embodiments of the invention, as seen in conjunction with the following drawings.

25

Brief Description of Drawings

Fig. 1 is a prior art fluid delivery system, shown diagrammatically.

Fig. 2 is a fluid delivery system of the present invention, shown diagrammatically.

30

Embodiments of Invention

Fig. 1 is a view of the prior art fluid delivery system 10 described above. The system 10 includes a reservoir 12 containing ink 13 that is delivered through a tube 14 protected in a chain guide 15 to a print head 16 that moves in both directions A and B along the printer width 17.

5 Fig. 2 is a view of the pressure balanced loop fluid delivery system 20 using many of the conventional components, including reservoir 12, ink 13, print head 16 moving back and forth (directions A and B) along printer width 17. Tube 14 of system 10 is replaced by inlet tube 22, a first tee intersection 23, two loop tubes 24 and 25, protected by chain guides 26 and 27, respectively, to a
10 second tee intersection 28, and an outlet tube 29 from intersection 28 to print head 16.

The pressure balanced loop fluid delivery system 20 eliminates the need for an air pocket or bladder inside the print cartridge or an external reservoir to absorb pressure fluctuations due to acceleration and deceleration. This is done
15 by using a continuous loop of fluid line (the combination of tubes 24 and 25) with a tee 23 for the inlet from inlet tube 22 connected to reservoir 12, and another tee 28 for the outlet to final tube the print head cartridge 16.

In system 20, fluid is free to circulate within the loop of tubes 24 and 25 when set in motion by acceleration or deceleration of the print cartridge 16.
20 If the print head 16 is at rest and then suddenly accelerates to the right (Direction B), the fluid will circulate counter clockwise through the loop of tubes 24 and 25 and tees 23 and 28. Likewise if the print head 16 accelerates to the left (Direction A), the fluid will circulate clockwise through the loop of tubes 24 and 25 and tees 23 and 28.

25 There will be little or no pressure change in the print head cartridge 16 when compared to the conventional single sided unbalanced system 10. Another benefit of the balanced loop system 20 is that the fluid resistance within the loop (23-25, 28) is less, because there are two fluid lines 24 and 25 in parallel in the loop section (23-25,28). This can reduce pressure drops caused by high flow
30 rates when printing image areas with a high fluid demand. When compared to the conventional single sided unbalanced system 10, the additional cost of the balanced

loop system is very small. Only an additional length of hose carrier guide chain 27, fluid line 25, and two tee fittings 23 and 28 are needed.

While Fig. 2 shows the loop (23-25,28) in a vertical orientation, there is no reason why the loop could not be laid out horizontally. In some printer configurations, the horizontal loop configuration would be easier to implement than the vertical loop configuration.

While limited to a particular theory, the solution to this problem in the art can be explained using the "unsteady" Bernoulli equation in the theory of fluid dynamics, the pressure variation found during acceleration of a print head 16 in system 10 can be described as:

$$\Delta P = (a/g) * L$$

where P is pressure measured in height of water in meters, a is acceleration of the fluid measured as m/sec², g is the gravitational acceleration also in m/sec², and L is length of fluid in the tubing measured in m at the moment of acceleration. In the system 10 seen in Fig. 1, the length of fluid in the tubing is about 0.1 m when the print head 16 is fully moved in direction B but is about 1 m when the print head 16 is fully moved in direction A. Conservatively, one can assume that the acceleration is 1.0 m/sec² which is 1/10 of gravitational acceleration on Earth.

When the print head 16 starts from right to left (direction A from a terminal position after full movement in direction B), the change in pressure, ΔP , will be -0.01 (m of water). But when the print head 16 starts from left to right (direction B from a terminal position after full movement in direction A), the change in pressure, ΔP , will be 0.1 (m of water). Thus, one change in pressure is a negative number, while the opposite direction reversal provides a positive change in pressure that is ten times higher.

With negative pressure needed for operation of the print head 16, typically about -0.02 --- -0.05 (m H₂O), the pressure variation resulting from the direction B motion can be much higher and cause the negative pressure to fall out of specification for good image quality, particularly at the edge of the imaged medium.

With a delivery system 20 of the present invention, use of the above “unsteady” Bernoulli equation will be zero because the fluid within loop components 23-25, 28 will circulate freely therein with the result that there is no pressure variation in any part of the motion of print head 16 along either direction A or direction B. When the print head 16 starts from the terminal left position and moves along direction B to the right, the pressure variation in loop tube 24 would be positive while at the same time, the pressure variation in loop tube 25 would be negative at the same value. Therefore, because it is impossible for the common fluid to have an increase and decrease in pressure at the same time, the pressure can only be unchanged at the terminal left position. The same is true for the terminal right position.

The tubes 22, 24, 25, and 29 can be made from material disclosed in International Patent Application Serial No. US97/09106 (Koehler et al.). In that application, an ink jet ink fluid line comprises polymeric tubing having an ink-contacting surface of poly(ethylene) or poly(tetrafluoroethylene).

The system 20 as seen in Fig. 2 has been implemented in an Olympus IJP3600 inkjet printer together with an ink delivery system disclosed in PCT Publication WO97/10106 (Lee et al.). Printing results were compared between this system 20 and a conventional system 10 as seen in Fig. 1. The above analysis was confirmed.

The invention is not limited to the above. The claims follow.

What is claimed is:

1. A fluid delivery system, comprising a pressure balanced loop of tubing containing fluid therein.
5
2. The system of Claim 1, wherein the loop of tubing comprises an inlet tube, an inlet tee intersection connected to the inlet tube, two loop tubes each connected to the inlet tee intersection, a outlet tee intersection connected to the two loop tubes, and an outlet tube.
10
3. The system of Claim 2, wherein the inlet tube terminates in a reservoir of fluid and wherein the outlet tube terminates in a reciprocating fluid dispensing device.
- 15 4. The system of Claim 2, wherein the two loop tubes are each protected by a chain guide.
5. The system of Claim 3, wherein the loop of tubing provides no pressure variation for the fluid being delivered, during abrupt movements of the
20 print head of acceleration or deceleration.
6. The system of Claim 3, wherein the fluid is ink and wherein the reciprocating fluid device is a inkjet print head.

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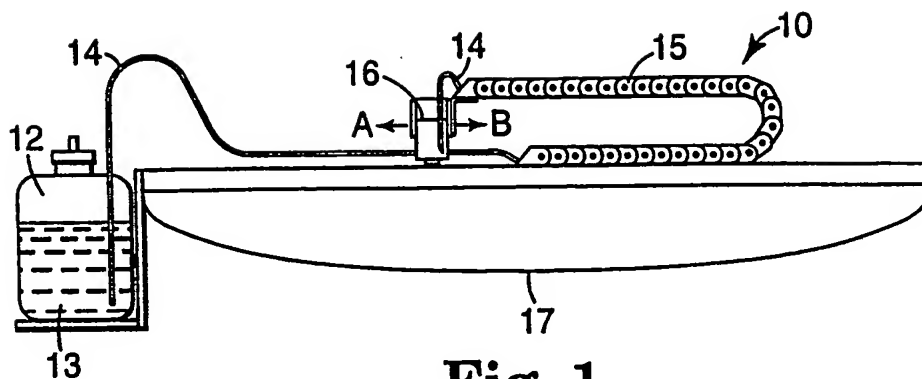


Fig. 1
(PRIOR ART)

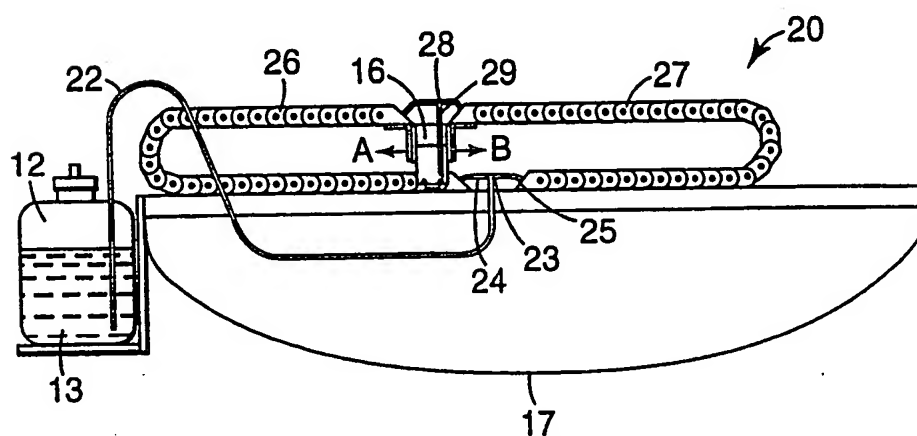


Fig. 2

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/13827

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B41J2/175

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B41J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 719 608 A (SABONIS CHARLES J ET AL) 17 February 1998	1,2
Y	see the whole document ---	3-6
Y	US 5 469 201 A (ERICKSON PAUL R ET AL) 21 November 1995 cited in the application see the whole document ---	3-6
X	US 4 422 086 A (MIURA MASAYOSHI ET AL) 20 December 1983 see the whole document ---	1-3,5,6
X	US 4 527 175 A (KOJIMA TAMOTSU ET AL) 2 July 1985 see the whole document ---	1
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3. Document member of the same patent family

Date of the actual completion of the international search

5 October 1998

Date of mailing of the international search report

14/10/1998

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/13827

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 373 435 A (STRONG ROGER K) 12 March 1968 see the whole document ---	1
A	US 4 929 963 A (BALAZAR LEONARD) 29 May 1990 see abstract; figure 3 ---	1
A	US 5 159 348 A (DIETL STEVEN J ET AL) 27 October 1992 see abstract; figures 1,2 -----	1

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information on patent family members

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